The EMCC/DARPA*Massively Parallel Electromagnetic Scattering Project

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Abstract

The Electromagnetic Code Consortium (EMCC) was sponsored by the Advanced Research Program Agency (ARPA) to demonstrate the effectiveness of massively parallel computing in large scale radar signature predictions. The EMCC/ARPA project consisted of three parts:

PRDA A two-phase Program Research and Development Announcement was issued to parallelize existing Computational Electromagnetics (CEM) codes in Phase I, downselect the Phase I codes based on accuracy, scalability, and computational speed, and demonstrate the increased CEM capability in Phase II on a generic fighter size model (VFY218) with and without material treatments at the frequency of approximately 1 GHz. Six codes were chosen for Phase I which included the finite volume time domain based RCS3D; the hybrid FDTD/FVTD; moment method based AIM, ParaMoM, and MM3D-DP; and the hybrid finite element/integral equation based SWITCH. These codes were downselected to two, RCS3D and AIM, in Phase II.

NRA & National Labs A simultaneous technology development effort was undertaken through a NASA Research Announcement (NRA) to complement the algorithm development of the PRDA codes. Five grants and five contracts were issued to Universities and Companies for technology development. One of the five contracts was awarded to Lockheed Fort Worth Company to support the project by developing improved surface meshing and surface meshes for the VFY218 from the EMCC CAD system, ACAD. In additional to the NRA participants, two DOE National Laboratories, Livermore and Sandia, also participated in the technology development effort.

MPP Computer A Massively Parallel Processing (MPP) computer, an Intel Paragon, at the Numerical Aerodynamic Simulator Facility (NAS) of the NASA Ames Research Center was upgraded and used for code development and demonstration. This MPP computer had 208 i860 GP nodes.

Phase I of the PRDA and the NRA and National Labs work has been completed. The NAS Paragon was transferred to ARPA in August 1995.

Overall, the project has greatly increased the CEM capability in both algorithmic and parallel computing aspects. Especially, parallel computing has become a common and vital tool in several U.S. Aerospace Companies for large scale radar signature predictions.

1 Introduction

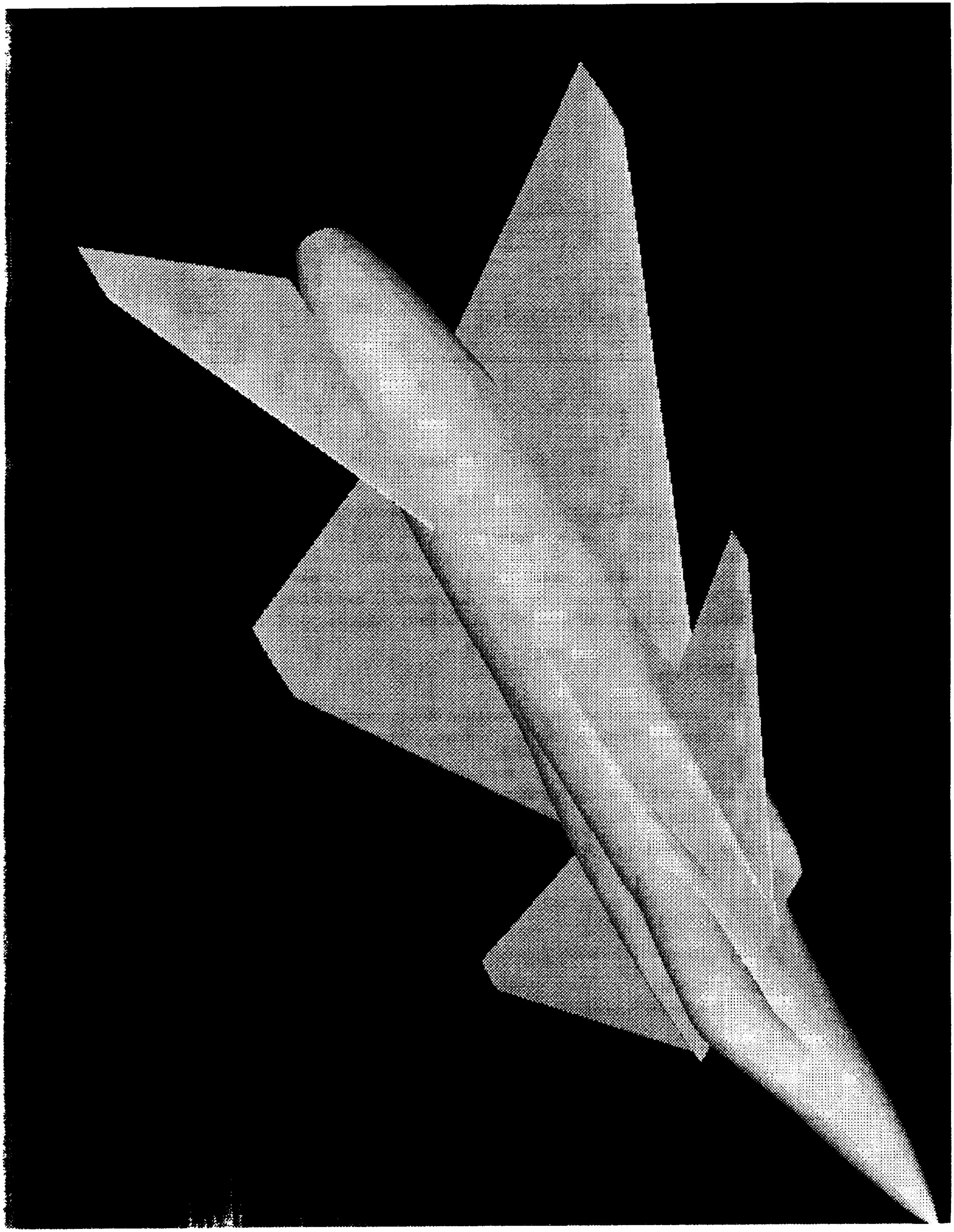
The Electromagnetic Code Consortium (EMCC) received funding from Advanced Research Program Agency (ARPA) to significantly advance the state-of-the-art in computational electromagnetics (CEM) using massively parallel computing systems. The specific objectives of this EMCC/ARPA project are to (a) migrate ARPA sponsored parallel computing technology to current CEM techniques, (b) develop and demonstrate a major increase in CEM capability, and (c) spearhead the development of new computational methods and physical modeling techniques that incorporate high levels of parallelism. The first two objectives were pursued by the Air Force Wright Laboratory through the Program Research and Development Announcement (PRDA) [1]. Parallel to the Air Force PRDA effort, the third objective is pursued by the NASA Ames Research Center under a separate NASA Research Announcement [2] and funded efforts at DOE Laboratories. In addition, a third aspect consisted of providing a massively parallel processing (MPP) computing resource for the project. This was supplied by the Numerical Aerodynamic Simulator Advanced Parallel Processing Facility at the NASA Ames Research Center.

The PRDA program was carried out in two phases. The objective of Phase I (Sept. 93 - March 94) was to conduct an evaluation of the most promising existing CEM codes that offered a potential to accurately and efficiently predict radar cross section (RCS) of a full scale fighter size aircraft. Six codes were selected for Phase I. They included the finite volume time domain (FVTD) based RCS3D [3] (Rockwell Science Center), the hybrid FDTD/FVTD [4] code (Lockheed Missile and Space Company), the method of moment (MOM) based AIM [5] (Rockwell North American Aircraft Division), ParaMoM [6] (Syracuse Research Corporation), MM3D-DP [7] (Lockheed Advanced Development Company), and the finite element (FEM) based SWITCH [8] (Northrop B-2 Division). These existing codes were ported to massively parallel computers and were benchmarked using generic EMCC test cases [9]. At the end of Phase I, these codes were down selected based on accuracy, scalability, and computational speed. RCS3D was initially chosen to proceed to phase II (June 94 - Nov. 95). With additional funds, AIM was also chosen for Phase II development (March 95 - Feb. 97). The objective of Phase II is to conduct a large scale demonstration. Codes selected for Phase II will either implement advanced algorithms developed under the PRDA effort, or those developed under the NASA NRA effort. The codes are then used to predict the full scale RCS of a generic fighter model with and without material treatments at a maximum frequency of 1 GHz. At 1 GHz, the size of the full scale fighter model is approximately $50\lambda \times 30\lambda \times 13\lambda$. The material treatments included MagRam coating on both sides of the tails for one configuration and MagRam coating on both sides of the tails and the upper surfaces of the wings and canards for the other configuration. An actual 1/30th scale model, VFY218 (shown in Figure 1), built by Lockheed Fort Worth Company was donated to the EMCC for the use of this project. The radar cross section (RCS) of the VFY218 model were measured [10, 11, 12] to provide the validation data.

The NRA technology development effort was accomplished through five university grants and five contracts to companies. The university participants included University of Illinois at Urbana for the fast MOM algorithm development [13]; University of Illinois at Chicago for the development of spatial decomposition technique [14]; University of Michigan for the development of edge based FEM method [20]; Pennsylvania State University for improvements in time accurate modeling of materials and development of new FVTD algorithms [16]; and a joint team of the Ohio State University and Worcester Polytechnic Instituted for the development of edge based FEM method and Delauney mesh Generator [21]. The five contracts were awarded to McDonnell Douglas Company (MDC) for hybridizing FVTD technique (CFDMAXES) with MOM code (CAROLS-3D) [15]; CRAY Research Company for porting a finite difference time domain (FDTD) code to CRAY T3D and modeling time dependent complex materials [17]; General Electric CR&D for developing FEM method with hybrid nodal/edge elements [19]; Rockwell Science Center for developing an unstructured grid FVTD code [22]; and Lockheed Fort worth Company for enhancing surface mesh generation in ACAD and providing VFY218 CAD support for this project [18]. In addition to the NRA participants, two DOE National Laboratories, Livermore and Sandia, also participated in the technology development effort. Sandia's task was to parallelize CARLOS-3D for Intel Paragon systems [23]; and Livermore's task was to optimize a parallelized, unstructured mesh finite surface time domain code [24].

A Massively Parallel Processing (MPP) computer, an Intel Paragon, at the Numerical Aerodynamic Simulator Facility (NAS) of the NASA Ames Research Center was upgraded and used for code development and demonstration for this project. This MPP computer had 208 i860 GP nodes with 32 MB of memory per node. This computer was transferred to ARPA in August 1995 when Phase I of the PRDA and the NRA and National Labs efforts were completed. The remaining PRDA Phase II code development and demonstration work will be accomplished through the use of the various DoD High Performance Computing computers, such as the Paragon at Wright-Patterson Air Force Base and the IBM SP2 at the Maui High Performance Computing Center.

This report provides the programmatic and technical overview of the EMCC/ARPA project. A schedule summarizing the activities of this project is shown in Table 1. Section II discusses the six PRDA codes, their theoretical bases, capabilities, and limitations. Section III describes the theoretical and code development under NRA



Activities	1993	1994				1995			
	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
AF PRDA									
Phase I	⟵ Port ⟶								
Downselect			⟷						
Phase II				⟵ VFY218 Demo ⟶ ···					
NASA NRA & NL	New Algorithms & Modeling								
MPP Computers	⟵ NAS Paragon ⟶								
						⟵ DoD HPC Computers — ···			

Table 1: Project Schedule

effort. The National Lab work is presented in Section IV. Technical details of the PRDA, NRA, and national lab efforts can be found in the reports listed in the reference section. Finally, Section V summarizes additional ongoing CEM research and development efforts, such as hybrid asymptotic/CEM developments, Fast Multipole Method development and Fast Solvers which are funded by ARPA or other government agencies and have been concurrently developed with this project.

2 PRDA

Topic: Development and Implementation of Computational Electromagnetic Techniques on Massively Parallel Computing Architectures

Phase I Goal: Port existing codes to MPP computers and validate with the EMCC benchmark cases.

Phase II Goal: Model Full Scale PEC and Treated Fighter Configurations at near 1 GHz.

2.1 PRDA Phase I

2.1.1 Rockwell Science Center

Code: RCS3D

Rockwell Science Center: (PI: Vijaya Shankar)

Start Date: 9-15-93 **Completion Date:** 7-15-94 (Complete)

RCS3D was developed by Rockwell International Science Center. This code is based on the finite volume time domain method (FVTD) widely used by the computational fluid dynamics community. The code solves three dimensional time domain Maxwell equations in differential conservation form using the characteristic-based method. The code uses a structured grid in which the physical domain is divided into body-conformal finite volume cells. These cells are then mapped to a uniform computational grid. The current implementation of the code provides for second order accuracy in both space and time. The characteristic based outer non-reflecting boundary condition is used to terminate the computation domain. This is done by setting the characteristic variables corresponding to the reflected wave at the outer boundary to zero. Though this non-reflecting boundary condition is exact for one dimensional problems, it is approximate for two and three dimensional problems. The implementation of the characteristic boundary condition is quite different from that of the Mür's absorbing boundary condition, but it can be shown that the performance of these two boundary conditions are similar. The code currently can be used to model perfect electric conducting (PEC) bodies, dielectric regions, resistive sheets, and impedance layers. The theoretical computational complexity for this method is on the order of $N[O(N)]$ or $O(f^3)$ for memory requirement and $O(N^{4/3})$ or $O(f^4)$ for solution time, where N is the number of grid points and f is the frequency.

The code uses ACAD as a preprocessor to generate the surface grid of a geometry. The surface grid is then meshed using GRIDGEN (Government code) or UNISG (Rockwell code). Typically the grid density can be as high as 50 grid points per wavelength near singularities and 10 grid points per wavelength near the outer boundary. RCS3D was ported to nCUBE and Paragon during Phase I. It has one, two, and three dimensional capability within the same code. The excitation can be a pulse or a sinusoidal wave. The code can treat scatterers with periodic boundary condition and infinite ground plane. The RCS is obtained using near to far field transformation and fast Fourier transform (FFT).

2.1.2 Rockwell North American Aircraft

Code: Adaptive Integral Method (AIM)

Rockwell North American Aircraft Division: (PI: E.Bleszynski)

Start Date: 9-15-93 **Completion Date:** 12-31-94 (Complete)

Adaptive Integral Method (AIM) was developed by Rockwell International North

American Aircraft Division. It is based on the method of moments (MOM). It solves the system of linear equations using conjugate gradient method. However, instead of the $O(N^2)$ operations for a typical matrix-vector multiplication, AIM utilizes an innovative scheme to speed up the matrix-vector multiplication involved in each step of the iteration procedure. In this scheme, each current element is transformed into a set of charges which have the same order of multipole expansion as the current element and are located at the vertices of a uniform grid. The interactions between current elements is replaced by the interactions of the charges located on the uniform grid. Due to the stair-casing error introduced by the uniform grid, a correction matrix is added to correct the error. This correction matrix represents the difference between the impedance matrix built from the original current elements and the impedance matrix built from the charges on the uniform grid. This correction matrix becomes a sparse matrix if terms that are smaller than a certain percentage of the self terms are neglected. To summarize, let x represent the current unknowns, K the impedance matrix, and y the excitation vector. The matrix-vector multiplication becomes

$$\begin{aligned} x = Ky &= K^{uniform}y + \left(K - K^{uniform}\right)y \\ &= K^{uniform}y + K^{sparse}y. \end{aligned}$$

Recognizing that $K^{uniform}$ is Toeplitz and its Fourier transform is diagonal, the above multiplication can be carried out by

$$x = F^{-1}\left[F(K^{Toeplitz})F(y)\right] + K^{sparse}y \tag{1}$$

The operation count to multiply $F(K^{Toeplitz})$ with $F(Y)$ is $O(N)$, where N is the number of unknowns. So is the operation count for $K^{sparse}y$. The operation count for performing FFT and inverse FFT is $O(NlogN)$. Thus, the computational complexity for the AIM method is $O(NlogN)$ or $O(f^3 \log f^3)$ for both the memory requirement and solution time.

The code accepts any triangulated surface facet files such as those generated by ACAD. The code was ported to a Paragon during Phase I. It uses Galerkin electric field integral equation (EFIE), magnetic field integral equation (MFIE), and combined field integral equation (CFIE) formulations. The code currently has PEC, IBC, and resistive sheet implementations although this code can be extended to handle any geometry and material, such as volumetric regions of complex ϵ and μ and anisotropic regions, that can be modeled with any MOM type code. Currently, this code only uses surface elements. The capability of this code can be enhanced by including linear and volume elements. The code calculates both monostatic or bistatic RCS.

2.1.3 Northrop B-2 Division

Code: SWITCH

Northrop B-2 Division: (PI: Maurice Sancer)
Start Date: 9-15-93 **Completion Date:** 7-15-94 (Complete)

SWITCH was developed by Northrop B-2 Division. The code was named SWITCH as it was the intention of the developer to make the code switchable among pure finite element (FEM) formulation, pure integral equation (IE) formulation, or a hybrid of the FEM and IE formulation. However, due to lack of a proper absorbing boundary condition at the radiation boundary, the pure FEM version has never been implemented. The code was also named SWITCH because the code can be used as a scattering code or an antenna radiation code. Unfortunately, the antenna radiation portion of the code was not part of this PRDA effort. This code uses edge-based vector field expansion on three dimensional curvilinear brick for the FEM portion of the code and curvilinear quadrilateral patches for the IE portion. The code currently uses roof-top basis functions but is amenable to higher order basis functions. The accuracy of the solution can be controlled through the conformal integral equation termination at the radiation boundary. This code can handle arbitrary material, such as inhomogeneous anisotropic electric and magnetic material, bulk radar absorbing material, anisotropic IBC coating, through the FEM portion of the code. The computational complexity of the code is $O(N_D^2)$ or $O(f^4)$ for the memory requirement and $O(N_D^3)$ or $O(f^6)$ for the solution time. N_D is the number of unknowns of the dense matrix corresponding to the IE formulation. N_D is typically smaller than the number of unknowns required by a flat facet type MOM code.

The code uses ACAD or NCAL (Northrop code) as the preprocessor to generate the required surface grid. The surface grid is then input to PATRAN to generate the neutral files of the quadrilateral patches and hexahedral cells. The code was ported to an iPSC/860 during Phase I. It has Galerkin EFIE, MFIE, and CFIE implementations. It also has an option to include infinite ground plane into the geometry. The output of the code is monostatic or bistatic RCS.

2.1.4 Syracuse Research Corporation

Code: PARAMOM-MPP

Syracuse Research Corporation: (PI: Chung-Chi Cha)
Start Date: 9-15-93 **Completion Date:** 3-15-94 (Complete)

ParaMoM was developed by Syracuse Research Corporation. It is a moment method based code. It uses curved triangles that conform to the surface curvature instead of flat triangular surfaces as the basis function domains. The basis function is defined in terms of a general surface parameterization. This feature allows for the simple, module inclusion of several different parameterizations into the code. The computational complexity of the code is $O(N^2)$ or $O(f^4)$ for the memory requirement and $O(N^3)$ or $O(f^6)$ for the solution time. The number of unknowns N is typically smaller than that of a flat facet based MOM code.

The code accepts IGES bicubic and NURB surfaces, as well as flat triangular patches. The code also reads geometry files generated from SCAMP, a CAD package developed by Syracuse Research Corporation based on PLOT10 library. The code was ported to a Paragon, a CM5, and an IBM SP1 during Phase I. Portability of the code was the main goal of this effort. Thus, the structure of the code was built with ease of out-of-core matrix fill and ease of interface to various matrix solvers in mind. The code currently has Galerkin EFIE, MFIE, and CFIE implementations. The parallelized version of ParaMoM is based on the serial ParaMoM 1.0 version which can treat PEC objects, as well as objects with surface impedance and resistive card. The new serial ParaMoM 2.0 version which has more material modeling capability will become available in the near future. Up to three planes of symmetry can be applied to save computer memory requirement. The code also includes wires which can be separated or connected to surfaces. Scattering or radiation due to these wires can be computed. The output of the code is monostatic or bistatic far-field RCS or antenna radiation pattern.

2.1.5 Lockheed Advanced Development Company

Code: MM3D-DP

Lockheed Advanced Development Company: (Vaughn Cable)
Start Date: 9-15-93 **Completion Date:** 7-15-94 (Complete)

MM3D-DP was developed by Lockheed Advanced Development Company. This code is also a moment method based code. It uses Rao, Wilton, and Glisson triangular rooftop basis functions with triangular flat surfaces as the basis function domains. The integral equation is based on the equivalent surface formulation and only Galerkin EFIE is implemented. All junction and boundary conditions are automatically generated to satisfy continuity conditions. The material modeling capability of this code includes PEC body, homogeneous region, isotropic region, lossy dielectric of complex ϵ and μ, anisotropic surface impedance coating, and IBC coating. The computational complexity of this code is $O(N^2)$ or $O(f^4)$ for the memory requirement and $O(N^3)$ or $O(f^6)$ for the solution time, where N is the number of unknowns.

This code uses I-DEAS, PATRAN, or STRIM as a preprocessor to generate the required surface mesh. The code was ported to an iPSC/860 and a Paragon during Phase I. Intel Pro-Solver DES out-of-core slab solver was used to solve the matrix equation. Symmetry plane option can be applied to save computer memory. The output of this code is RCS and surface currents.

2.1.6 Lockheed Missiles and Space Company

Code: LMSC_FVTD
Lockheed Missile and Space Company: (PI: Kane Yee)
Start Date: 9-15-93 **Completion Date:** 7-15-94 (Complete)

Hybrid FDTD/FVTD code was developed by Lockheed Missile and Space Company. This code is a hybrid of the finite difference time domain (FDTD) based on the line-surface integral form of Maxwell's equations and the FVTD based on the surface-volume integral form of Maxwell's equations. This code uses a body-conformal three dimensional grid near the surface of the scatterer to reduce the staircasing error and an overlapping uniform grid elsewhere to reduce the computer memory requirement. The body-conformal grid contains three layers and can be constructed from a structured or an unstructured surface grid. The fields are located on staggered E and H grids with fields defined at the vertices instead of the edges. The fields are then interpolated between the uniform and body-conformal grids during the time stepping procedure. The code originally used Mür's second order absorbing boundary condition. But it was found to be very inefficient when implemented on massively parallel computing systems. Thus, a new radiation boundary condition with a damping function which appears as a multiplicative factor in the filed update equations was developed. The result is at least as good as Mür's second order absorbing boundary condition but much more efficient to implement on massively parallel computer systems. Though the idea of using overlapping grids is conceptually simple, it can not readily handle geometries with sharp edges and tips due to difficulties in interpolating fields between the two grid systems. The computational complexity of this method is proportional to $O(N)$ or $O(f^3)$ and the solution time is proportional to $O(n^{4/3})$ or $O(f^4)$, where N is the number of grid points.

The code requires a surface grid as input. The code then generates three layers of prism cells from the surface of the scatterer. Currently, sharp edges and tips are modeled with staircase grids. Theoretically, the method this code is based on should allow modeling of arbitrary material. But currently only PEC and impedance boundary condition (IBC) coating modeling capabilities are implemented in the code. The code was ported to a MASPAR machine during Phase I. The output of the code is RCS.

2.2 PRDA Phase II

2.2.1 Rockwell Science Center

Code: RCS3D

Rockwell Science Center: (PI: Vijaya Shankar)
Start Date: 6-1-94 **Completion Date:** 11-31-95(Incomplete)

RCS3D was chosen to proceed to phase II. In phase II, the code was further improved by implementing optimal load balancing and symmetry plane option. A preprocessing utility, RCSPREP, which specifies the input parameters associated with the targets and look angles, was developed to make the code more user friendly. The formulations for singularity treatments for thin wire and gaps were developed but not implemented in the code. The code was used to calculate the RCS of the VFY218 at various frequencies up to 1 GHz for the PEC and coated configurations. There were two coated configurations. One configuration has MagRam coating on the upper surfaces of the wings and canards and both sides of the tails. The other configuration has MagRam coating on both sides of the tail.

Though the structured grid based code is efficient and has better data structure, the multizone gridding process is tedious and time consuming. Besides, interpolation between adjacent zones at the interface boundary degrades execution efficiency. Furthermore, it is difficult to grid certain interior regions. Thus in Phase II, the development of an unstructured grid version was initially planned. The unstructured grid will make it easier to generate grids for all regions and to implement higher order basis functions. The unstructured grid code can also better handle singular regions through choices of basis functions. The disadvantage for unstructured grid will be the increased bookkeeping and memory requirement. However, during the course of this development, it was found that the current second order accurate algorithm used in the structured grid code gives gross inaccuracy when used with an unstructured grid. This has prompted the need to further investigate the algorithms for unstructured grids and their error analysis. These tasks will be carried out in a separate NRA effort which started in January 1995.

2.2.2 Rockwell North American Aircraft

Code: Adaptive Integral Method (AIM)
Rockwell North American Aircraft Division: (PI: E.Bleszynski)
Start Date: 2-28-95 **Completion Date:** 2-28-97 (Incomplete)

AIM was chosen to proceed to Phase II. Initially, only half of the fund for Phase II was available. Thus, Phase II was split into two 10-month subphases with an additional 4 months for documentation. The objective of the first subphase is to further improve the AIM code. The improvements include: adding symmetry plane option; solving for multiple right-hand-side solutions; developing formulations for volumetric and linear elements; visual display for material and current for pre- and post-processing. Later, additional funding became available to fully fund the second subphase as well. The objective of the second subphase is to predict the radar signatures of the VFY218 at frequencies up to 1 GHz for the PEC and coated configurations.

3 NRA

Goal Develop new technology to impact PRDA codes in 1994-5.

Duration All contracts were initially for 15 months beginning 10-1-93

3.1 Univ. of Illinois - Urbana

Topic: Novel Fast Method of Moments (MOM) algorithms
Univ. of Illinois - Urbana Prof. W. Chew
Completion Date: 12-31-94 (complete)

The principal investigator was Prof. Weng Cho Chew. The original proposal was directed toward further development of fast integral equation methods, RATMA, NEPAL and other nested recursive methods. However, in the course of this grant, contributions were made toward the Berenger Perfectly Matched Boundary Conditions in 3D as coordinate stretching, directional and multi-level improvements to the Fast Multipole Method and 3D volume integral equations and curvilinear Method of Moments. The delivered codes and documents are shown below.

```
This directory consists of compressed tar files on the following topics
of research under the supervision of Professor Weng Cho Chew at the
University of Illinois, Urbana, IL 61801.  Most the codes are developed
on the SUN workstation, with a few examples developed for the Connection
Machine CM-5.
```

3DCGFFT.tar 3D inhomogeneous body solver using FFT method. This code uses $O(N)$ memory and $O(NlogN)$ operation count per iteration for one right-hand side.

cfiefmm3d.tar 3D metallic scatterer using combined field integral equation and fast multipole method. This code uses $O(N^{1.33})$ memory and $O(N^{1.33})$ operation count per iteration for one right-hand side.

faffa2d.tar 2D metallic scatterer using fast far field approximation. It uses $O(N)$ memory, and $O(N^{1.33})$ operation count per iteration for one right-hand side. Several thousand wavelengths problem has been solved with this code.

mlfma2d.tar 2D metallic scatterer for both Ez and Hz polarization using multilevel fast multipole algorithm. It uses $O(NlogN)$ memory and $O(Nlog^2N)$ operation counts.

nepal3d.tar 3D nested equivalence principal algorithm (NEPAL) for inhomogeneous body. The codes are for both the SUN workstation and the Connection Machine CM-5. This method requires $O(N^{1.33})$ memory and $O(N^2)$ operation count. It is a direct solver yielding solution for all incident waves.

pml3d.tar 3D perfectly matched layer (PML) code using 3D FDTD Yee algorithm. This code runs on the Connection Machine CM-5. Over a million unknowns have been solved with this code, getting throughput of several GFLOPS.

raima3d.tar 3D recursive aggregation interaction matrix approach (RAIMA) for inhomogeneous body. This code requires $O(N^{1.67})$ memory and $O(N^{2.33})$ operation count. It is a direct solver yielding solution for all incident angles.

rpfma2d.tar 2D metallic scatterer solver using ray propagation fast multipole approach (RPFMA). It uses $O(N^{1.33})$ memory, and $O(N^{1.33})$ operation count per iteration for one right hand side.

Some of the relevant publications may be found in the publication list of W.C. Chew [13].

3.2 Univ. of Illinois - Chicago

Topic: Spatial Decomposition Technique (SDT) of MOM problems into subzones
Univ. of Illinois - Chicago Prof. Umashankar
Completion Date: 6-31-95 (complete)

The co-principal investigators are Professor Korada Umashankar and Sharad Laxpati. The Spatial Decomposition Technique developed by Prof. Umashankar is a modification of the usual volume based One-Level Abutting Domain Decomposition with either Point-Jacobi or Gauss-Seidel Iterations. The difference in the surface formulation in SDT is the addition of fictitious boundaries and unknowns to further communications between domains and possibly improve the conditioning of the subdomains. The SDT was implemented in a prototype MOM code on the NAS Paragon and SP-2. In the limited number of test cases run, the iterative convergence occurred in approximately 10 iterations so no attempt was made to use multigrid or direct substructuring techniques.

3.3 McDonnell Douglas Company

Topic: Hybrid Finite Volume Frequency Domain (FVTD) with MOM (CARLOS-3D/CFD).
McDonnell Douglas Company R. Agarwal & D. Wang
Completion Date: 12-31-94 (complete)

The co-principal investigators were Ramesh Agarwal and Dau-Sing Wang. This effort hybridized an existing MOM code with an existing FVTD domain code CFD-MAXES. To accomplish this, a parametric quadrilateral patch (Q-Patch) formulation was developed and added to CARLOS-3D/Q, the time domain CFD based CFDMAXES code was modified to frequency domain and additional materials capability was added, and a Hybrid Code was developed based on Neumann B.C. coupling. The following issues were solved during this development

- coupling between a direct matrix solver for the surface MOM and an iterative solver for the volume FVFD code.
- unmatched gridding system
- different mesh density requirements
- unmatched basis functions

The capabilities of these codes is summarized in Table 2.

CODE	CARLOS-3D/Q^{tm}	CFDMAXES^{tm}	Hybrid Code
freq-domain	yes	yes	yes
time-domain	-	yes	-
geometry	3D	3D and 2D	3D
geometry input	std CAD/AGM files	std CFD grid system	std CAD/AGM std CFD grids
mesh	quadrilateral patches triangular facets	curvilinear cubic cells	quadrilateral patches curvilinear cells
boundary conditions	PEC, dielectric, resistive R-card, impedance sheets	PEC, dielectric resistive,R-card	PEC, dielectric, resistive R-card, impedance sheets
output data per run	mono or bi-static RCS single or multi-freq single or multiple plane-cut all 4 polarizations	bistatic RCS single freq single plane-cut one polarization	bistatic RCS single freq single plane-cut two polarizations: VV, HH
near field	yes	yes	yes
body symmetries	one plane	two planes	none

Table 2: Capabilities of McDonnell NRA Codes

3.4 Pennsylvania State Univ.

Topic: Improvements in time accurate modeling of materials and new FVTD algorithms.
Penn State Univ. (Prof. R. Luebbers and L. Long):
Completion Date: 12-31-94 (complete)

The co-principal investigators were Prof. Ray Luebbers and Lyle Long. This grant worked in a large number of areas.

Non-reflecting Boundary Conditions A uniform matrix formulation for common ABC's, Mur, Higdon, Liao and stabilized forms of these.

CM Fortran FDTD Code A very fast SIMD version of FDTD was ported to the NAS CM-5.

CFD Methods in CEM A four-stage Runge-Kutta explicit time stepping method coupled with fourth order accurate spatial differencing.

Thin Dielectric Coating in FDTD A surface impedance BC for one-dimensional problems with thin, high permittivity, low-loss dielectric coatings on a PEC for one frequency at a time.

Frequency-Dependent Dispersive Media The recursive convolution approach to model dispersive materials was improved to be second order accurate and compared favorably to the differential approach.

Anisotropic Materials If the permittivity and conductivity tensors can be simultaneously diagonalized, the staggered Yee method can be extended to anisotropic media. A formulation for co-located **E** and **H** fields was developed.

3.5 CRAY Research

Topic: Finite Difference Time Domain (FDTD) on CRAY T3D and time dependent modeling of complex materials.
CRAY Research (Prof. A. Taflove and Steve Barnard):
Completion Date: 12-31-94 (complete)

The co-principal investigators were Prof. Allen Taflove and Steve Barnard. This contract encompassed three topics: porting of a FDTD3D to the CRAY T3D, FDTD modeling of dispersive media, and the extension of the Berenger Perfectly Matched Layer Boundary Condition.

Port of FDTD3D The explicit shared memory programming style with assembly language kernels was used to obtain 24Mflops/PE. The main difficultly consisted of load balancing for the absorbing boundary conditions (and any internal boundaries).

Dispersive Media Simpler multi-resonances material ODE based time accurate model was developed.

Berenger PML BC During this contract, J.P. Berenger published 2D absorbing boundary layer conditions which were extended to 3D and waveguides.

3.6 Lockheed Fort Worth Company

Topic: Enhanced Surface Mesh Generation in ACAD (and VFY218 support)
Lockheed Fort-Worth (J. P. Abelanet):
Completion Date: 12-31-94 (complete)

This contract differs from the other NRA efforts in that it primarily provided capabilities in the EMCC CAD system which supported the other activities. There were six tasks.

Enhanced Surface Meshing Automatic surface meshing for non-manifold B-rep solid geometry was integrated into existing semi-automatic and manual meshing tools. A simplified user interface for all meshing was also developed.

VFY218 Support Several files including ACAD, IGES, meshed facet files and images of the Lockheed donated VFY218 configuration were provided. These included untrimmed surface models and facetizations at various densities.

Generic Facet File Format Previously the ACAD facet file contained vertex locations, facet connectivity, material reference tags, edge and wedge identification and component tags. The new 9.0 facet file now contains vertex normals, vertex parametric coordinates (PARAMOM uses this feature.), vertex and facet identifiers, directions of principle curvature (XPATCH uses this feature.).

Material Attributes Improved materials modeling was added to ACAD, including the ability to apply material to individual facet, material orientation, two-sided materials and custom materials. These attributes are written to a file which can be referenced by the generic facet file.

BRL-CAD Optimization The BRL-CAD translator was modified to ignore details which do not meet a minimum surface area requirement.

Documentation Updated ACAD User's Manual, Technical Manual and Meshing Training Manuals were generated. For the first time, postscript versions of these manuals are now on-line with the program.

Three versions of ACAD 9.0a were delivered for IRIX4.0, SOLARIS2.3 and SUNOS4.1. Two additional ACAD bugfix versions were delivered to the EMCC. Version 9.0c is distributed by the EMCC.

Most codes work from the ACAD facet file definition (Section 18 of the reference manual.) Here is a short description of that file.

```
Line    Description
A       Revision          Date/Time        Machine
B       NP = Number of Parts (I5)
C       Name of Part      (String)
D       MIRROR=0 (no) =1 (A B C D where Ax +By +Cz =D) (I1,4(1x,f8.6)
E       NV = Number of vertices in current part (I7)
F       X Y Z   (2(F14.6,1x),F14.6) (NV times)
G       NSP = Number of Sub-parts
H       Sub-part Name    (string)
I       ET NSE NSV EM2 VP VN EC (I3,I7,I7,4I3)
        ET= element type(Edge=2,Tri=3,Quad=4,Para Tri=6,Tet=44,Hex=812)
        NSE = Number of elements in current subpart (always nonzero)
        NSV = Number of vertices in current subpart (non zero if VP=1 or VN=1)
        EM2 = Set to 1 if 2-sided material field and 0 otherwise
              When =1, line N will have 3 material fields instead of 1
        VP  = Set to 1 if vertex parameters are present, 0 otherwise
```

```
            Line K present only if set to 1
        VN  = Set to 1 if vertex normals are present, 0 otherwise
            Line L present only if set to 1
        EC = Set to 1 if element curvature lines present, 0 otherwise
            Line M present only if set to 1
K       U V VID Parametric vertex coordinate
L       Nx Ny Nz VID 3D Unit vector pointing away from interior of part
M       Min Max MnVx MnVy MnVz MxVx MxVy MxVz
            Min/Max are principal curvatures at facet center, and rest directions
N       V1 V2 M (M1 M2)
            V1,V2 indices of subpart vertices if NSV !=0, otherwise part vertices
            M (M1 M2) number of material property associate with element
```

3.7 General Electric CR&D

Topic: Nodal based Finite Element Method (FEM).
General Electric CR&D (J. D'Angelo):
Completion Date: 2-28-95 (complete)

The principal investigator was John D'Angelo. The goal of this work was the development of hybrid edge/nodal elements for sharp PEC boundaries to correct accuracy difficulties with a pure node based FEM based on the gauge enforcement method which solves

$$\nabla \times \frac{1}{\epsilon_r} \nabla \times H - \nabla \left(\frac{1}{\epsilon_r \mu_r} \nabla \cdot \mu_r H \right) - k_0^2 \mu_r H = 0.$$

In addition, a portable parallel version of RF3D was developed based on recursive coordinate bisection domain decomposition and a parallel Quasi-Minimal Residual (QMR) solver.

Accuracy problems with PEC edges and vertices were never fully resolved in 3D.

3.8 Univ. of Michigan

Topic: Edge Based Finite Element Method (FEM).
Univ. of Michigan (Prof. J. Volakis):
Completion Date: 12-31-94 (complete)

The principal investigator was Prof. John Volakis. This grant further developed an Edge Based FEM code, FEMATS, and new absorbing boundary conditions. In addition, FEMATS was parallelized on a KSR-1 and Paragon.

README

femats.bench.tar.Z is a compressed tar file containing the benchmark runs mentioned in Appendix E of this manual.

femats.cray.tar is a tar file containing the source code and test files for the CRAY version of FEMATS.

femats.doc.tar.Z is a compressed tar file containing the documentation for all of FEMATS (LaTeX and .ps formats).

femats.ksr.tar is a tar file containing the source code and test files for the KSR version of FEMATS.

femats.paragon.tar is a tar file containing the source code and test files for the Intel Paragon version of FEMATS.

femats.preproc.tar is a tar file containing the source code and test files for the workstation-based portion of FEMATS.

3.9 Ohio State Univ./Worcester Polytechnic Institute

Topic: Edge Based FEM, Delauney Mesh Generation.
Ohio State Univ./Worcester Polytechnic Institute (Prof. R. Lee/ Prof. J. Lee)
Completion Date: 6-30-95 (complete)

3.9.1 Ohio State University

The co-principal investigators were Prof. Robert Lee and Fusun Ozguner. The goals of this work were the parallelization of an edge-based Finite Element Code with Mei-style boundary conditions on the Intel Delta. Under this work, all-to-all communication schemes for a 2D mesh and a parallel QMR iterative solver were developed. The Mei-style absorbing boundary conditions did not prove effective and the Berenger Absorbing Boundary Layer described in the next section was incorporated in the code.

WEFD_DD.tar.z 558018 WEFD is an edge_based FEM code for solving scattering problems of plane waves incident upon perfect electric conducting objects. WEFD is a sequential code that generates the FEM matrix and its right-hand sides, decomposes the domain for the parallel solver csrcpxd, and calculates the scattered far field after the solution is obtained.

parallel_QMR.tar.z 362755 csrcpxd is the parallel solver that solves the FEM equations given by WEFD. It uses a parallel version of the Quasi-Minimal Residual (QMR) method written by Freund and Nachtigal. *ascii_bind* is a program that converts the data files generated by WEFD from ascii to binary so that they can be read by csrcpxd on Delta.

manual.ps.z 36608 A postscript file of the manual that details the various codes in this package, explains how to run each code, and explains the format of the data files.

readme 315 Few instructions on how to uncompress the previous codes.

3.9.2 Worcester Polytechnic Institute

The principal investigator was Prof. Jin-Fa Lee. The main thrust of this effort was to develop an automated unstructured mesh generation capability, entitled **TETRA**. This consisted of three efforts, surface meshing, *TriSURF*, initial Delauney tessellation, *PreTETRA*, and mesh refinements, *PostTETRA*, and quality improvements, *NiceMESH*. The outline of the system is shown below.

Surface Triangulation, PreTETRA .

- Edge point distribution
- Interior point distribution using normal-offsetting method
- Delaunay triangulation using Circle-Swapping technique
- Optimize Mesh Quality

Initial Delaunay Mesh Generation, PreTETRA .

- Bounding box and analytical meshing
- Watson-Boyer Algorithm for Delaunay Mesh
- Preserving surfaces by stitching
- Assigning attributes

Mesh Refinements, PostTETRA, and Quality Optimization, NiceTETRA .

- Symbolic meshing for point insertion
- Mesh refinements
- Optimize mesh quality

After substantial work, all of the EMCC test cases were run through the TETRA system. The most difficult part was obtaining a good Delaunay surface mesh.

In addition to the geometry, an extension to the Berenger Perfectly Matched Absorbing Layer was developed as an anisotropic absorbing media. Unfortunately, the formulation requires an orthogonalizing coordinate system but it does extend the PML to Finite Elements.

3.10 Rockwell Science Center

Topic: Finite Volume Time Domain Unstructured Mesh CEM
Rockwell Science Center: Vijaya Shankar
Start Date: Jan 18, 1995.
Completion Date:Jan 18, 1996, 12 month contract

The principal investigator is Dr. Vijaya Shankar. The goals of this work are (1) accuracy and stability study of different algorithms employing central, upwind, or upwind-biased spatial operators and different multistep time discretization procedures, (2) massively parallel implementations to run on different platforms such as the Intel Paragon, nCUBE, CRAY T3D and the IBM SP-2, (3) validation of results for the EMCC test targets, and (4) demonstration of the code for the VFY-218 fighter.

4 National Lab Selection

4.1 Sandia National Laboratory

Topic: Parallelized CARLOS-3D on Intel PARAGON.
Sandia National Laboratory (Raymond Zazworsky):

Completion Date: 6-30-95 (Complete)
Accomplishments:
In-Core SUNMOS parallel CARLOS-3D on the Intel SANDIA PARAGON won the Gordon Bell award, achieving over 100GFLOPS on the 150MHz VFY218 PEC problem. An out-of-core ProSolver DES version was built for OSF/1 OS on the PARAGON. Some work was done on incremental matrix

generation and general code improvements. Part of effort subcontracted to MDC.

4.2 Lawrence Livermore National Laboratory

Topic: Optimization of Parallelized, Unstructured Mesh Finite Surface Time Domain Code.

Lawrence Livermore National Laboratory (Niel Madsen):

Completion Date: 12-30-95 (Complete)

Accomplishments:

The Discrete Surface Integral formation is an extension of the Yee-scheme to unstructured meshes (and their duals) without any dissipation. This work incorporated the Penn. State University Absorbing Boundary Condition Formulation.

Due to difficulties with the Meiko computer, a limited number of EMCC test cases were validated. Furthermore, long time instabilities have appeared in some cases.

5 Conclusions

Several promising developments arose from parts of this program and are now under development by other agencies. Perhaps the most important development was a recognition that fast integral equation methods have the promise of the same computational complexity and cost as volume based methods with quantifiable accuracy. Here is a partial list of the other developments:

- Boeing Defense Systems/Syracuse Research Corporation received an award from ARPA for the integration of the Boeing Fast Multipole Method into the SRC ParaMoM code funded under this project.

- Intel Scientific Supercomputing Division/McDonnell Douglas Aerospace Corporation received an AFOSR contract to develop a hybrid version of CARLOS in conjunction with the Intel TurboSolver. The hybrid code will contain the CFDMAXES development funded under the NRA and the Intel code is an outgrowth of the Sandia parallelization of CARLOS-3D.

- University of Illinois-Urbana's MURI award from AFOSR stems from the NRA work done by W. Chew on fast integral equation methods.

- Rockwell Science Center developed CEM-based time-accurate Euler algorithms from the NRA contract to examine unstructured mesh algorithms.

Note: The title for references [3] - [8] is the same which is "Development and Implementation of Computational Electromagnetic Techniques on Massively Parallel Computing Architectures." Each reference is a five-volume final report, with Volume I being the Theory Manual. Volume II the User's Manual, Volume III the Porting Guide, Volume IV the Test Case Manual, and Volume V the Final Summary. These reports can be requested through the Defense Technical Information Center (DTIC).

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A EMCC DRAFT Charter

DOD/NASA/DIA ELECTROMAGNETIC CODE CONSORTIUM
CHARTER
MARCH 1995

A.1 BACKGROUND

Because of the individualized focus of aerospace applications using computational electromagnetics (CEM) for aircraft over the last 20 years, there was duplication in many organizations and little coordination among the developers. This resulted in a very expensive and slow development process. In an effort to rectify this situation, the Department of Defense (DOD) services and NASA proposed a joint organization to help coordinate CEM development in the U.S. for signature prediction. Out of this recommendation, the Electromagnetics Code Consortium (EMCC) was formed and the charter signed in 1987. The EMCC government executive committee was originally comprised of single representatives from each of the three DOD services, the Defense Intelligence Agency (DIA), and NASA (five charter members). The EMCC membership was made up of organizations from industry, members of the academic community, and Government laboratories.

The EMCC charter has been revised to better define goals and objectives, the management, and operation policy of the EMCC. This change is an effort to better focus the activities of the EMCC on the application requirements as defined by DOD users and industry and to expand the executive committee to include more government organizations.

A.2 GOAL AND OBJECTIVES

The goal of the EMCC is to develop and transition basic computational electromagnetics (CEM) research activities to effectively support the applications users. This includes the development of basic CEM technology, baseline codes, validation tools and data, benchmark cases, and validation procedures for CEM technologies. The primary focus of the EMCC is electromagnetic scattering and radiation problems for the entire electromagnetic spectrum with growth into coupling, remote sensing and biomedical applications.

The specific objectives of the EMCC are to:

1. Coordinate Tri-Service CEM Requirements and R&D

    - Prepare and submit CEM investment strategies to the Joint Directors of Laboratories.

- Conduct common interest technology developmental programs.
- Execute joint procurement actions for economy of scale.

2. Code Development and Dissemination

   - Develop and refine a suite electromagnetic codes for radiation and scattering.
   - Establish a central location for the dissemination of codes.

3. Reduce System Life Cycle Costs.

   - Minimize experimental testing using CEM.
   - Use CEM for design, retrofit, mission planning, and survivability and vulnerability analyses.

4. Promote Technical Interchange and Transfer

   - Create a forum for the exchange of technical information among CEM technologist and the discussion of common concerns and interests pertinent to DOD computational electromagnetics applications.
   - Encourage technology transfer to industry from Government organizations and academia.

5. Develop Validation and Verification Benchmarks

   - Develop and maintain nationally recognized standards and procedures for validation and verification of analysis codes, models,
   - Establish a central location for the dissemination of codes.

6. Reduce System Life Cycle Costs.

   - Minimize experimental testing using CEM.
   - Use CEM for design, retrofit, mission planning, and survivability and vulnerability analyses.

7. Promote Technical Interchange and Transfer

   - Create a forum for the exchange of technical information among CEM technologist and the discussion of common concerns and interests pertinent to DOD computational electromagnetics applications.

- Encourage technology transfer to industry from Government organizations and academia.

8. Develop Validation and Verification Benchmarks

    - Develop and maintain nationally recognized standards and procedures for validation and verification of analysis codes, models, and the application of CEM for DOD systems.

9. Provide a Government Expert Advisory Resource

    - Provide the DOD acquisition and research, development, test, and evaluation (RDT&E) communities with expert advisory resources for evaluation and testing of operational and development systems.

A.3 MANAGEMENT

The management structure of the EMCC consists of 5 interrelated groups, Government Advocacy Group, Government Executive Committee, Industry / Academia Advisory Committee, Technical Working Groups, and Support Contractor(s). The management structure is outlined in Figure 1.

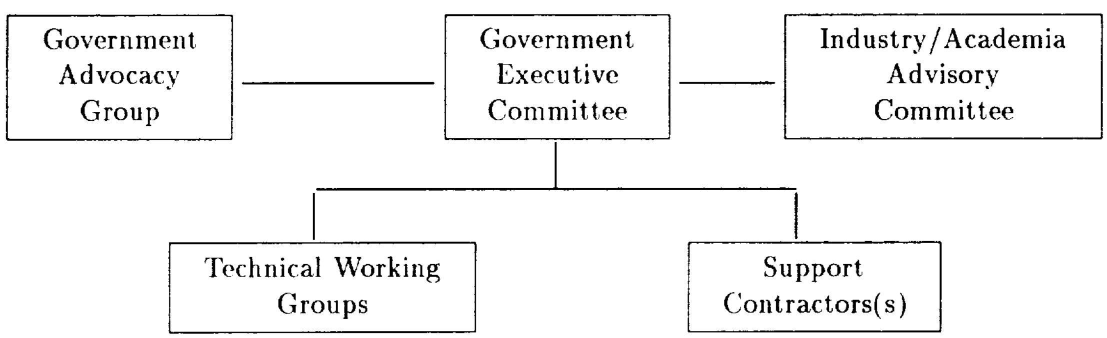

Figure 1. EMCC Management Structure

The Government Executive Committee (GEC) is responsible for the operation of the consortium and translation of guidance from the Government Advocacy Group, and recommendations from the Industry / Academia Committee and Technical Working Groups into long term CEM roadmaps. The GEC is composed of members from various Government organizations. Each participating organization will be represented by up to two members who will provide management and technical support to the EMCC. Each GEC member organization shall contribute a yearly membership fee of $20,000 to provide funding for EMCC technical, contract and administrative support.

The management function includes developing and implementing the EMCC roadmap and interfacing with the Government Advocacy Group and the Industry / Academia Advisory Committee. They shall be responsible for policy decisions and for planning and conducting EMCC business.

The technical function includes: leading or participating in the Technical Working Groups, evaluating codes, monitoring contracts, and conducting and documenting validation measurements. The technical function shall also include the development of technical CEM roadmaps. The technical function of the GEC requires a one-quarter person-year of technical support.

The Government Advocacy Group (GAG) consists of headquarters level representatives from NASA, DOD Services and agencies and intelligence organizations. The Advocacy Group will support the long-term goals and objectives of CEM R&D to meet the needs of their organizations, advocate the use of the EMCC to coordinate CEM development, and foster the financial support of the EMCC.

The Industry / Academia Advisory Committee (IAAC) consists of executives and senior researchers with wide experience in CEM research, applications, and projects. This Advisory Committee assists the GEC in developing CEM roadmaps and provides industry's perspectives on CEM requirements and advocacy for the EMCC.

The Technical Working Groups (TWGs) will be formed as required to cover the inherent disciplines of CEM such as integral methods, differential methods, infrared, etc. The TWG consists of representatives from the Government, industry, national laboratories, and academia. Each TWG is tasked to develop benchmark cases, technology assessments, and standards in support of their disciplines. Collectively, the TWGs will identify prioritized critical technology development areas and make recommendations to the GEC.

The Support Contractor (s) will distribute geometric models and codes and data, provide training, contracting and administrative functions, and technical support.

A.4 GENERAL MEMBERSHIP

EMCC general membership is open to all U.S. citizens who are EM researchers and developers in the U.S. All parties interested in becoming a member of the GEC, Industry/Academic Advisory Committee, and/or the TWG are welcome and should contact a current GEC member for details on how to join. Each member is approved by one member of the GEC. Continued membership requires active participation at annual meetings, TWGs, and/or the IAAC without reimbursement from the EMCC. Membership entitles a member, for a nominal fee and subject to security constraints, to obtain data, codes, training and support as provided by the EMCC.

The following guidelines apply to their representative groups/committees.

1. GEC members pay yearly dues and provide Government technical support to the EMCC. The GEC members have voting rights in directing funds managed by the EMCC. Each GEC organization shall have one vote. All GEC members shall have a security clearance at the Secret or higher level. The chairperson of the GEC will rotate among the GEC members on a yearly basis, with the NASA representative serving as the initial chairperson. The new GEC chairperson will be selected at the annual meeting.

2. Government Advocacy Group members are invited members of the EMCC. Invitations are determined by the GEC.

3. The Industry / Academia Advisory Committee members are invited by the GEC for a period of two years. The chairperson of the Industry / Academia Advisory committee will be selected by the members of the committee on an annual basis.

4. TWG members are drawn from the general membership of the EMCC. Each TWG shall have co-chairpersons who are selected by the TWG members on a yearly basis. The co-chairperson positions are jointly held by a non-government and a government representative.

A.5 OPERATING PLANS

The EMCC research operating plan will be driven by the requirements of Government and industry users of CEM. A current assessment of these requirements will be maintained and incorporated into a CEM roadmap which will be the basis for identifying the technical areas to be pursued. The EMCC will strive to develop EM basic research in CEM , which is common to multispectral applications, and validate and distribute CEM codes. The EMCC will not seek to develop production applications per se. These tasks will be left to the government and industry organizations. Initially, only RF scattering and radiation will be considered by the EMCC. Further development of the basic EM and multispectral technologies in other areas will be

Multispectral Applications	EM Basic Research	Implementation Research	Validation	Products and Support
Scattering	Theory	Hardware	Benchmarks	Distribution
Radiation	Physical Models	Software	Measurements	Support
Sys Integration	Algorithms	Chips	Geometry	Enhancements
Sensor Fusion	-Integral	CAD/Grids	Analytical	User Groups
Biomedical	-Differential	Visualization	Code-to-Code	Documentation
Device Design	-Hybrid Stand	Range-to-Range		Training
Remote Sensing	-Asymptotic		Methodology	Portability
Coupling			Errors	Installation
				Commercialization
				Modeling
				Environment

Table 3: EMCC Span of Development

future growth areas of the EMCC. The general areas of research are listed in Figure 2.

In the EM basic research area, which includes theory, physical modeling techniques and algorithms, the EMCC will maintain a current assessment of the research being conducted under Government sponsorship within industry and the university community. The users' requirements will be compared to this ongoing research roadmap to identify the basic EM research technology to be pursued by the EMCC as funds become available. These technology requirements will also be made available to the 6.1-funded Government organizations in an effort to solicit their support for this basic research. The EMCC will select, develop, and validate baseline codes to be used as test-bedsS for new algorithms and technology development.

The Implementation Research area will be leveraged through the adaptation of technologies developed by other technical disciplines. For example, grid generation techniques are being developed in the computational fluid dynamics (CFD) and the infrared (IR) communities. Other similar technologies include graphical display software, and computer design environments. In the implementation research area, the EMCC will develop and recommend standards for geometry description, generation and transfer and standards for coding and code documentation.

The Validation effort will focus on developing standard benchmark cases and the generation of the experimental data bases. The EMCC will provide and develop validation measurements criteria and procedures. Special attention will be paid to acquiring data from a number of ranges and conducting range-to-range comparisons. The EMCC will also provide an assessment of the available codes through code-to-code comparisons along with the comparisons to experimental data.

The EMCC will provide distribution and support for baseline codes through user groups, phone support, and training. This support function is intended to be self-supporting and provide some funding for bug fixes and enhancements. In addition, members of the EMCC will be encouraged to jointly propose and develop products for distribution and validation by the EMCC, although support will be provided by the developing organization. Future EMCC support will depend upon the code being selected as a baseline code by the EMCC.

A.6 SECURITY

All material produced by the EMCC, or through its sponsorship, shall be protected and dispersed in accordance with current DOD security directives and International Traffic and Arms Regulations.

A.7 EMCC MEETINGS

A.7.1 Meeting Schedules

1. The EMCC, as a whole general assembly, shall hold at least one regular meeting each calendar year. Special meetings shall be called as required depending on user and supporting organization requirements.

2. GEC meetings or teleconferences shall take place at least once each quarter at a mutually agreed upon location and times.

3. The Industry and Academia Advisory committee meetings shall take place at least once a year in conjunction with the regular EMCC general assembly meetings. Special meetings may be called by the GEC.

4. The TWG meetings shall take place at least once a year in conjunction with the regular EMCC general assembly meetings. Special meetings may be called by the GEC chairperson.

A.7.2 Meeting Notices

1. The regular annual meeting agenda shall be distributed by the EMCC Chairperson at least 8 weeks prior to the meeting.

2. The agenda for special meetings shall be distributed at least 1 week prior to the meeting.

B EMCC Members

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_________/  \    _ARMY_  EMCC   _NAVY_      /  \______
AIR FORCE    \  /                      \  /     NASA
              \/                        \/
            ELECTROMAGNETIC CODE CONSORTIUM
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This is the the Electromagnetics Code Consortium (EMCC) E-mail digest.
The purpose of the E-mail digest is to inform the EMCC community of the
activities and issues of the Consortium. The official EMCC mailings
can be obtained from Wright Labs. To be placed on the official
mailing list an individual must be sponsored by a member of the
government executive committee of the EMCC:

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C Deliverables

Deliverables

1	./NLAB/livermore
1	./NLAB/sandia
2	./NLAB
88	./NRA/CRAY/code
216	./NRA/CRAY/doc/theory
4225	./NRA/CRAY/doc
2	./NRA/CRAY/results/almond
1	./NRA/CRAY/results/cylinder
2	./NRA/CRAY/results/slab
3	./NRA/CRAY/results/wedge_pec
3	./NRA/CRAY/results/wedge_ram
10	./NRA/CRAY/results
4323	./NRA/CRAY
1002	./NRA/GE/doc
3843	./NRA/GE
1	./NRA/IL-Chicago
1965	./NRA/IL-Urbana
59	./NRA/LFWC/IRIX4.0/airfoil
82	./NRA/LFWC/IRIX4.0/bugbuster
5128	./NRA/LFWC/IRIX4.0/conv
14	./NRA/LFWC/IRIX4.0/cursor
44	./NRA/LFWC/IRIX4.0/fonts
5	./NRA/LFWC/IRIX4.0/icons
103	./NRA/LFWC/IRIX4.0/print
8	./NRA/LFWC/IRIX4.0/rms
4123	./NRA/LFWC/IRIX4.0/training9.0
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13064	./NRA/LFWC/IRIX4.0
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82	./NRA/LFWC/SOLARIS2.3/bugbuster
6731	./NRA/LFWC/SOLARIS2.3/conv
12	./NRA/LFWC/SOLARIS2.3/cursor
45	./NRA/LFWC/SOLARIS2.3/fonts
2	./NRA/LFWC/SOLARIS2.3/icons
8	./NRA/LFWC/SOLARIS2.3/print

8	./NRA/LFWC/SOLARIS2.3/rms
2847	./NRA/LFWC/SOLARIS2.3/training9.0
1	./NRA/LFWC/SOLARIS2.3/util
13024	./NRA/LFWC/SOLARIS2.3
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45	./NRA/LFWC/SUNOS4.1/fonts
2	./NRA/LFWC/SUNOS4.1/icons
8	./NRA/LFWC/SUNOS4.1/print
8	./NRA/LFWC/SUNOS4.1/rms
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465	./NRA/LFWC/document/postscript/training_manual
8280	./NRA/LFWC/document/postscript/user_guide
14	./NRA/LFWC/document/postscript/final_report
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337	./NRA/LFWC/document/src/MISC
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3	./NRA/LFWC/document/src/NMB/misc
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57	./NRA/LFWC/document/src/bin
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283	./NRA/LFWC/document/src/com
4253	./NRA/LFWC/document/src
22096	./NRA/LFWC/document
33280	./NRA/LFWC/vfy218
94878	./NRA/LFWC

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5913    ./NRA/McD/documentation/final_report
271     ./NRA/McD/documentation/theory_report
121     ./NRA/McD/documentation/users_manual
30      ./NRA/McD/documentation/install_porting
6336    ./NRA/McD/documentation
339     ./NRA/McD/carlos
15176   ./NRA/McD
609     ./NRA/Michigan
23      ./NRA/PSU/ss/diel
21      ./NRA/PSU/ss/pec
44      ./NRA/PSU/ss
27      ./NRA/PSU/trans
520     ./NRA/PSU/doc
648     ./NRA/PSU
4544    ./NRA/OSU
2284    ./NRA/WPI/jlee/EXAMPLES/emcc1
1707    ./NRA/WPI/jlee/EXAMPLES/emcc10
3991    ./NRA/WPI/jlee/EXAMPLES
47      ./NRA/WPI/jlee/NiceMESH
104     ./NRA/WPI/jlee/PreTETRA_V.2
92      ./NRA/WPI/jlee/bin
105     ./NRA/WPI/jlee/TETRA
4358    ./NRA/WPI/jlee
8442    ./NRA/WPI
134430  ./NRA
273     ./PRDA/lmsc/lmsc
3989    ./PRDA/lmsc
2402    ./PRDA/ladc/mm3d/examples
1486    ./PRDA/ladc/mm3d/src
3900    ./PRDA/ladc/
6679    ./PRDA/src
28      ./PRDA/risc/mppdoc
1       ./PRDA/risc/mpptest/host
1       ./PRDA/risc/mpptest/node
2       ./PRDA/risc/mpptest
393     ./PRDA/risc/rcsmpp/slave
1       ./PRDA/risc/rcsmpp/master
394     ./PRDA/risc/rcsmpp
1047    ./PRDA/risc
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2419    ./PRDA/northrop
14135   ./PRDA
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2969    ./codes/carlos3d
394     ./codes/ram2d
14330   ./codes
336     ./measurement/RCS/bin
21169   ./measurement/RCS/tape3
3142    ./measurement/RCS/test
69169   ./measurement/RCS/tape1
48      ./measurement/RCS/util
86969   ./measurement/RCS/tape2
51192   ./measurement/RCS/conesphere
528     ./measurement/RCS/vfy218/dist
33688   ./measurement/RCS/vfy218
14858   ./measurement/RCS/plots
4524    ./measurement/RCS/crypts
295092  ./measurement/RCS
295092  ./measurement
492965  .
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